COUNTING SEALS; ESTIMATING THE UNSEEN FRACTION USING A COVARIATE AND MARK-RECAPTURE MODEL

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COUNTING SEALS; ESTIMATING THE UNSEEN FRACTION USING A COVARIATE AND CAPTURE-RECAPTURE MODEL

A

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ABSTRACT

We evaluated the influences of environmental covariates on the proportion of harbor seals (*Phoca vitulina richardsi*) ashore on Tugidak Island using a series of photographic capture-recapture experiments and ground based counts. We used general linear models to examine the significance of combinations of covariates including quadratics terms. Time of day, tide height, rate of tide change, surf, and wind speed significantly influenced the number of seals ashore during the molting period. The model including all significant covariates best explained the probability of seals being hauled out. We observed a decline in the local population using the haulout suggesting that seasonal migration affects the number of seals ashore. The relationship between covariates and the number of seals hauled out on Tugidak Island differ in some respects from those reported at other sites in Alaska, implying that a region wide application of a single correction factor to counts of hauled out harbor seals may not adequately account for seals at sea.

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INTRODUCTION[1]

In Alaska, population size and trends of harbor seals (*Phoca vitulina richardsi*) are primarily assessed using aerial and ground-based counts of seals on terrestrial haulouts or glacial ice (Pitcher 1990, Mathews and Kelly 1996, Withrow and Loughlin 1996, 1997, Frost et al. 1999, Jemison and Kelly 2001, Boveng *et al.* 2003, Small *et al.* 2003, Ver Hoef and Frost in press). Although the precision of these counts may be high, they underestimate the true population size, because an unknown fraction of the population at sea cannot be directly counted (Frost *et al.*1999, Huber *et al.* 2001, Boveng *et al.* 2003, Small *et al.* 2003, Adkison *et al.* in press). Interpreting counts of harbor seals ashore relies either on estimating correction factors for the uncounted proportion of the population (Yochem *et al.*1987, Withrow and Loughlin 1996, 1997, Olesiuk 1999, Huber *et al.* 2001) or on comparing counts under standardized survey conditions (Frost *et al.* 1999, Boveng *et al.* 2003, Small *et al.* 2003, Ver Hoef and Frost in press).

The fraction of the population ashore on Tugidak Island (56°27'N, 154°46'W) is likely seasonally influenced by biological requirements such as parturition and molting (Jemison and Kelly 2001). The daily movement of seals onto land or ice may be controlled by thermal constraints, prey availability, and predator avoidance (Watts 1992, Nordstrom 2002). It is possible to explain some of the seasonal and diurnal variation in the number of seals ashore through statistical analysis of covariates such as date, time of day, stage of tide, and weather conditions (Pauli and Therhune 1987, Frost *et al.* 1999, Jemison and Kelly 2001, Boveng *et al.* 2003, Small *et al.* 2003, Ver Hoef and Frost in

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[1] Moran, J.R., M.D. Adkison, and B.P. Kelly; prepared for submission to Marine Mammal Science

press). In Alaska, the greatest numbers of seals are ashore during the low tides of August (Frost *et al.* 1999, Boveng *et al.* 2003, Small *et al.* 2003), and statewide harbor seal population surveys are traditionally conducted then (Withrow and Loughlin 1997, Frost *et al.* 1999, Boveng *et al.* 2003, Small *et al.* 2003, Ver Hoef and Frost in press).

Logistical limitations and environmental variability frequently result in seal surveys being conducted under less than optimal conditions, leading to unrepresentative, low counts (Withrow and Loughlin1996). The Alaska Department of Fish and Game (ADFG) has adopted a covariate approach to estimate harbor seal population trends (Frost *et al.* 1999, Small *et al.* 2003). The effects of factors influencing haulout behavior such as date, stage of tide, time of day, and weather conditions during surveys were modeled so that counts could be standardized for comparison across diverse survey conditions (Frost *et al.* 1999, Small *et al.* 2003, Ver Hoef and Frost in press). These standardized counts are an index of abundance; abundance itself is not estimated.

Section 117 of the Marine Mammal Protection Act mandates stock assessments (i.e., abundance estimates) for harbor seal populations in Alaskan waters (Barlow *et al.* 1995). Estimating abundance requires estimating the proportion of seals ashore. The National Marine Fisheries Service (NMFS) has developed correction factors based on radio telemetry data o account for seals not ashore during aerial surveys. Several weeks prior to the survey period, seals are captured and marked with radio transmitters (Withrow and Loughlin 1996). During survey flights, the ratio of marked animals ashore to the total number of transmitters deployed was used to correct counts for the fraction of the population remaining in the water.

The use of radio transmitters for estimating the proportion of seals at sea during a census does have some limitations. The number of transmitters deployed is limited by the number of animals that can be captured and tagged and by the number of transmitters that can be successfully monitored during a survey flight. Not all haulout sites are suitable for capture; thus, variation in behavior between sites may not be detectable. There is a potential for behavioral changes associated with capture and tagging (Seber 1982). Unequal capture probabilities of different ages and sexes could lead to a unrepresentative sample during a survey period (Huber *et al.* 2001). Critical to this approach is determining the exact reason that radio tagged animals are not detected during a survey. If, in addition to not detecting animals at sea, some animals are missed because of transmitter failure, dispersal from the study area, or failure to detect seals ashore, the correction factor will be biased.

Recent work has revealed an additional complication with estimating harbor seal populations and trends from counts of seals ashore. The seasonal timing of molting differs among age-sex classes on Tugidak Island (Daniel *et al.* 2003). Thus, not only does the fraction of the population ashore vary with date, but the demographic composition of the seals ashore may also vary as the molting period progresses (Thomson and Rothery 1987, Härkönen and Harding 2001, Daniel *et al.* 2003).

Photographing the natural markings of seals and whales has been used as a non-invasive method to identify individuals and catalog animals over time (Hiby 1990, Mizroch *et al.* 1990, Yochem et al 1990, Foracado *et al.* 1999, Foracado and Aguilar 2000, Crowley *et al.* 2001, Hastings *et al.* 200l). This technique allows the "marking" of large numbers of animals in a non-invasive manner. We improved upon the methods used to correct counts of harbor seals by combining a photographic capture – recapture experiment with ground-based counts of seals ashore for a single terrestrial haulout in the Gulf of Alaska. This allowed us to estimate the proportion of the population ashore as well as how various environmental covariates affected this proportion. We were thus able to standardize counts to absolute abundance rather than an index of abundance.

METHODS

Study Area

Tugidak Island is located in the Gulf of Alaska southwest of Kodiak Island. Approximately 30 km long and 9 km wide, Tugidak Island has several harbor seal haulouts along its shore. Historically Tugidak Island may have been one of the largest harbor seal haulouts in the world (Pitcher 1990). It is currently one of the best-studied sites in Alaska, with counts of seals ashore from as far back as the 1950's (Pitcher 1990, Jemison and Kelly 2001).

This study focuses on harbor seals ashore in discontinuous groups along a two to three mile stretch of the southwestern beach of Tugidak Island. Composed of sand to cobble substrate below 10-30 m bluffs, the beach extends approximately 75 m from the base of the bluffs at low tide. With the exception of extreme high tides or high tides in combination with high surf conditions, adequate area is available for all seals to haul out. From atop the bluffs, seals ashore can be photographed and precisely counted.

Photographic Capture

Compared to traditional marking methods such as dye, brands, flipper tags, or telemetry, photographic identification permits a large number of individuals to be identified at a low cost and with little disturbance to animals (Crowley *et al.* 2001). Recent advances in digital photography and a process for evaluating and winnowing images of seals, developed by Crowley *et al.* (2001), allowed us to catalog individual seals based on the distinctive pelage pattern of the ventrum using photographs supplied by a long-term photographic capture-recapture study initiated by the University of Alaska Southeast and the Alaska Department of Fish and Game (Crowley *et al.* 2001, Hastings *et al.* 2001). This methodology's high "marking" rate allowed us to use capture-recapture methods to estimate the total number of seals both onshore and temporarily at sea (Seber 1982). This method of photographically identifying individuals offers several advantages over marking methods; seals are not physically captured and there are no behavioral changes associated with photographic capture (Crowley *et al.* 2001). Unlike other protocols for photographic capture-recapture (Hiby and Lovell 1997), seals are not intentionally disturbed prior to or during photography.

During August and September of 2000, harbor seals were digitally photographed on Tugidak Island as part of an on-going long-term life history project (Hastings *et al.* 2001). For this project, a Nikon D-1 digital camera equipped with a Celestron C8 telescope lens (25 x power) was used to photograph the ventral surface of seals. The use of digital photography permitted greater flexibility than conventional film when faced with poor and rapidly changing light conditions, often encountered on Tugidak Island.

Photography was conducted from late morning through the afternoon, a period when seal activity on the beach was low and numbers ashore were generally high and stable.

Each day that seals were photographed was considered a capture period. The following day of photography was considered the recapture period. Observers began a capture period at one end of the haulout systematically assessing the position and pelage condition of each seal on the haul out for potential capture. We ensured that the sex of the animal was known and the same perspective used when matching photographs; only seals oriented with their ventrum towards the camera with head and hips clearly visible were used in our analysis (Crowley *et al.* 2001).

In some seals, fading of the pelage prior to the shedding of old hair obscured spot and ring patterns (Stutz 1967). These unidentifiable seals were categorized as "bleached". If properly oriented, bleached seals were not photographed and recorded as a "skip". If a seal's ventral markings were obscured by debris such as kelp or sand, the seal was not photographed and not included in the capture-recapture experiment. If there was any doubt whether the above criteria were being met, seals were photographed for later evaluation.

We minimized the potential for unknowingly photographing an individual seal more than once during each capture period (Stevick *et al.* 2001), by using only capture periods in which all of the seals hauled out were evaluated and suitable seals photographed. If excessive movement by the seals caused the observers to lose track of which seals had been assessed, the survey was omitted. Weather conditions unsuitable for photography or detrimental to equipment also resulted in incomplete surveys of the haulout. We omitted all incomplete surveys from our population estimates; seals tended to segregate by sex and age along the beach and thus an incomplete survey might not be a representative sample of the population.

Based on observations of known animals and the daily movements of seals on and off the beach, we assumed the length of time between capture and recapture (2 - 6 days) was long enough to have allowed seals to leave the beach, resulting in a remixing of the population prior to resampling. In some seals, bleaching of the pelage as molting progressed would have an effect similar to migration (seals would not be available for capture); by minimizing the interval between capture and recapture, we reduced the chance that deteriorating pelage condition would result in false negative matches. Restricting the time between capture and recapture also reduced the complications induced by phenomena such as immigration, emigration, mortality, or seasonal demographic shifts.

Matching Images

In order to "recapture" a seal, images of an individual seal from the capture period were compared to images from the recapture period. We developed a systematic method of evaluating images based on the photographic matching process used by Crowley *et al.* (2001). At the time of photography, we categorized seals by sex (male, female, and unknown) and color phases (dark, intermediate, and light) (Kelly 1981). This resulted in each image being placed into one of nine categories: dark phase males, dark phase females, dark phase unknown, intermediate phase male, intermediate phase female, intermediate phase unknown, light phase male, light phase female, and light phase unknown.

We visually matched images of seals captured during a day with images taken during the next photographic period, so long as it was no more than 6 days distant, using image-browsing software (ACDSEE ®, ACD Systems, LTD, Saanichton, BC). Photographs of seals with pelage color or sex that could not be unquestionably determined were compared with images of all possible categories. The image to be matched was displayed on one computer monitor, while all images of the corresponding category of the recapture period were sequentially displayed on an adjacent computer monitor. We evaluated the markings on the ventrum to determine if the images were of the same individual. In some cases, imaging software was used to reduce glare, brighten shadows, and enhance the contrast of images prior to matching.

Correction for False Negative Matches

Some problems associated with the use of natural marks include: matching animals that should not be matched (false positive), not matching animals that should be matched (false negative), and unknowingly photographing the same animal more than once during a capture period (false negative errors within a capture period) (Stevick *et al.* 2001). By systematically photographing relatively immobile animals and discarding capture periods in which seals were disturbed, we greatly reduced the chances of making false negative errors within a capture period. The pelage patterns of seals were complex and sufficiently distinct enough so that we could eliminate false positive matches between a capture period and recapture period through careful examination of matched photographs.

We initially screened photographs for image quality and proper orientation to reduce the probability of false negative matches between sample periods. Further evaluation of false negative matches required an estimate of the probability of not detecting a match. We estimated this probability using "double tagging" theory (Seber 1982). The same sets of images used for our population estimates were independently evaluated by Conservation Research Ltd. (Cambridge, UK)[2] following the method of Hiby and Lovell (1997). We treated images of seals recaptured by the two methods of photographic identification as independent "tags", each with a probability of not being detected (π).

The probability of not detecting a match "tag loss" during the recapture period using our protocols (π_B) was calculated following Seber (1982)(Appendix). We eliminated the bias generated by false negative matches between capture and recapture period, using this probability to inflate the number of photographically recaptured animals (m_2) for all capture-recapture analyses (Seber 1982)(Appendix).

Population Estimate

The number of seals available to come ashore on the southwestern beach of Tugidak Island during the 2000 molting period was predicted from a series of independent population estimates using the Chapman form of the Petersen estimator (Seber 1982):

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[2] Personal communication from Kelly Hastings, Alaska Department of Fish and Game, Division of Wildlife Conservation, 333 Raspberry Road Anchorage , Alaska 99518, U.S.A.

$$N^* = \left(\frac{(n_1 + 1)(n_2 + 1)}{(\hat{m}_2 + 1)} \right) - 1$$

where:

N^* = the population estimate.

n_1 = the number of seals photographed during a capture period.

n_2 = the number of seals photographed plus the number of properly oriented seals "skipped" due to poor pelage condition during a recapture period.

$\hat{m}_2$ = the estimated number of recaptures (seals from a capture period identified during a recapture period) corrected for false negative matches.

Seals photographed in a single day, a capture period, were matched to seals photographed during the next day of photography, the recapture period. Since a series of population estimates were made, the recapture period for an estimate became the capture period for the next population estimate. Images from a capture period were only compared to images of the subsequent recapture period. The normal approximation method was used to estimate 95% confidence intervals for each population estimate (Seber 1982) (Appendix).

Covariate Data Collection

In conjunction with the series of population estimates, we used a quasi-experimental approach to evaluate covariates influencing haulout behavior. Observational data suggested that time of day, tide height, rate of change in tide, surf, wind speed, wind direction, precipitation and cloud cover might influence the number of seals ashore. Although we could not control these variables, by selecting when to count seals ashore we were able to maximize the contrast in conditions, allowing separation of the influence of each factor on the proportion of seals hauled out.

We counted seals on the southwestern beach of Tugidak Island from 6 August 2000 - 24 August 2000 and from 30 August 2000 - 24 September 2000 one to seven times per day. From the bluffs overlooking the haulout, counts were made during daylight hours (0700 - 2330 local time) 131 times over 41 days. To increase contrast, an effort was made to stagger the starting time of counts. At the beginning of each count we recorded the covariates of interest. We also noted other factors possibly influencing the number of seals ashore, such as disturbances by humans or predators.

We used a hand held wind meter and compass to measure wind speed and wind direction from atop the bluffs. Direct measurements of wind conditions on the haulout beach were not taken because of a high potential for disturbing seals. Due to the complex nature of wind patterns associated with the bluffs, these measurements may not have accurately reflected conditions on the beach. During counts, wind speed ranged from 3 to 97 kph with a mean of 28 kph (S.D. = 18). The predominant wind direction during counts was west to northwest (270° - 315°); 69% of all counts fell within this range. For analysis, wind direction was transformed to the sine of (wind direction / 2).

To evaluate the effects of breaking waves on seals ashore, a relative scale from 1-5 was used to rate surf based on estimated wave height in meters, where:

1 = little to no wave action

2 = waves less than 0.5 m

3 = waves 0.5 m to 1.0 m

4 = waves 1.0 m to 2.0 m

5 = waves were 2 or more meters high.

Observers compared estimates of wave height throughout the study to ensure consistency. When more than one wave condition occurred during a count, an intermediate value was assigned. During counts, we observed waves ranging from 1 to 4.5.

Precipitation was categorized as the condition occurring during the majority of the count. A zero was recorded for no precipitation, a one for rain, and a two for snow/sleet/hail. If two conditions occurred for a roughly equal amount of time during a count, the category was split (*i.e.* 0.5 if rain started halfway through a count). Rain occurred during 10 counts and hail during one.

Temperature was recorded in degrees Celsius. Temperatures ranged from 9.4° C to 23.9° C with a mean of 13.9°C (S.D. = 2.2).

Tide height at the time of each count was taken from published National Oceanic and Atmospheric Administration observations at Women's Bay on Kodiak Island (approximately 190 km northeast of Tugidak Island). To estimate the rates of change in tide height during each count, we used the change in Women's Bay tide height over a 30-minute period.

Covariate Data Analysis

Because large estimation uncertainties resulted in biologically implausible short-term change in population size, we replaced the series of population estimates with a linear trend for the purpose of modeling the effects of the covariates on the proportion of animals ashore. We converted ground-based counts of seals ashore to the proportion of seals ashore by dividing each count by the population estimate from the trendline. Prior to covariate analysis, we used an arc sine transformation to approximate a constant variance (Dixon and Massey 1983, Huber *et al.* 2001) (Appendix).

One count of zero (caused by the interaction of a disturbance during high surf and tide conditions), which would have been an extreme outlier, was replaced with the next lowest count observed (a first-level Winsorization (Dixon and Massey 1983)) to prevent undue influence of this single observation (Figures 1-6).

The arc sine of the proportion of seals hauled out was predicted using a generalized linear model (Neter *et al.* 1996, Huber *et al.* 2001) using the statistical package S-plus 2000 ® (Insightful Corporation, Seattle, WA). Quadratic effects of each covariate were fit based on prior practice (Small *et al.* 2003, Adkison *et al.* in press) and a visual examination of our data (Figures 1 - 6).

$$\arcsin(p) = a_o + \sum_i (b_i x_i + c_i x_i^2)$$

where:

p = the estimated proportion of seals hauled out

x_i = the value of the covariate i (e.g., date, time of day, stage of tide).

a_o = the intercept.

b_i = the linear effect of the covariate i on the proportion of animals on the beach.

c_i = the quadratic effect of the covariate i on the proportion of animals on the beach.

We reduced the number of models compared by first building all possible single factor models and then used a likelihood ratio test on each to determine which covariates were statistically significant (Hilborn and Mangel 1997). Next, models containing all possible combinations of the significant covariates were fitted. We ranked the 32 models using the Akaike information criterion (AIC) (Burnham and Anderson 1998).

Day Effect

We determined if counts within a day were independent observations, by using analysis of variance (ANOVA) to compare the mean residual within a day to the mean residual for all counts. Because we found non-independence of observations from within the same day (see Results), the effective degrees of freedom in our data lay somewhere between the number of counts and the number of days. As a worst-case scenario, we recalculated all AIC values assuming the degrees of freedom depended on the number of days rather than the number of counts.

RESULTS

Photographic Capture-Recapture Experiment

Seals were photographed by the Alaska Department of Fish and Game on 5 occasions during August of 2000 and on 8 occasions during September of 2000 (Table 1). An initial evaluation of 3467 images of 1725 "individual" seals yielded 1687 "captured" seals. The number of individual seals photographed in a single day (n_1) ranged from 37 to 285 with a mean of 131. The number of individual seals photographically recaptured (n_2) ranged from 100 to 323 with a mean of 193. The number of seals photographed during a capture period and identified during the recapture period (m_2) ranged from 4 to 22 with a mean of 12 (Table 1).

The estimated probability of not detecting a recaptured animal while matching images of seals (π_B) was 0.12. To compensate for this error we inflated the number of recaptures (m_2) for each of our population estimates by a correction factor (Appendix) of 1.14 to obtain an estimated number of recaptures ($\hat{m}_2$).

A series of 11 Chapmanized Petersen estimates of the number of seals available to come ashore resulted in estimates ranging from 818 to 2495 seals with a mean of 1689 (S.D.= 447.1) (Table 1.). Because of large estimation uncertainties, we replaced the series of population estimates with a linear trend ($R^2 = 0.22$) (Figure 7). We also evaluated, and rejected, a quadratic trend in the population estimates (adjusted $R^2 = 0.14$). The linearized abundance values began with 1993 animals on 7 August and declined to 1288 on 21 September (Figure 7). Abundance estimates from this line were substituted for capture-recapture estimates in modeling covariate effects (see below). The average daily peak in the proportion of seals ashore ($n = 131$), when corrected using our linear population trend, was 51% (c.v. = 0.04).

Covariate Analysis

In August and September 2000, we completed 131 counts of seals hauled out on the southwestern beach of Tugidak Island. The mean number of seals observed on the beach was 717 (S.D. = 247). A peak count of 1129 occurred on 6 August 2000, and a minimum count of zero occurred on 19 September 2000.

In our initial screening of covariates, time of day, tide height, tide change, surf, and wind speed were found to be significantly related to the proportion of seals ashore. While the population estimates declined with date, the effects of date on the proportion ashore were not significant. Wind direction, temperature, cloud cover, and precipitation were also not significant covariates (Table 2).

Of the possible combinations of the significant covariates (32 models), the full model incorporating time of day, tide height, tide change, surf, and wind speed was the best explanation of the observed counts. Models with similar AIC (e.g. within 4 units) should also be considered plausible (Burnham and Andersen 1998); thus, a model that does not include wind speed cannot be discounted. Time of day was represented in the top 16 models, making it the most important factor in predicting the number of seals ashore (Table 3). Tide height was represented in the top four ranked models (Table 3). Coefficients and intercepts of the top two models evaluated are summarized in Table 4.

A diagnostic plot of the observed and predicted arc sine proportion of seals ashore using the model incorporating time of day, tide height, tide change, surf, and wind speed suggest a fairly good fit ($R^2 = 0.43$) with the exception of one outlier (Figure 8).

Day Effect

We found a significant difference between the mean value of residuals from different days, suggesting that counts within a day might not be independent (to illustrate the magnitude of the day effect, the absolute value of a typical day's mean residual was 0.11, more than half as large as the average absolute value of the residuals (0.17)). If we assumed the effective degrees of freedom were the number of days rather than the number of counts, the effect of wind speed was no longer included in the best model; the model including time of day, tide height, tide change, and surf ranked highest.

DISCUSSION

Our analysis of covariate effects and the proportion of seals ashore, derived from photographic capture – recapture population estimates, produced similar results as well as some important differences when compared to many of the techniques currently in use for evaluating harbor seal populations in Alaska (Withrow and Loughlin 1997, Frost *et* *al.* 1999, Boveng *et al.* 2003, Small *et al.* 2003, Ver Hoef and Frost in press). Peak counts of seals ashore during August and September generally followed a diurnal pattern, peaking in the afternoon and early evening. The numbers of seals ashore decreased during extreme low or high tides, rapidly rising tides, high surf, and high wind conditions.

The covariate relationships differ with regard to tidal influence and time of day from those reported at other sites in Alaska, implying that a region wide application of a single correction factor may not adequately account for seals at sea (Frost *et al.* 1999, Ver Hoeff and Frost in press). Unlike other researchers, we did not see an effect of date. This is likely because the effect we tested differs from that of other researchers. We found no effect of date on the proportion of animals ashore, whereas other researchers have found an effect of date on the numbers ashore. The number ashore is affected by the number of animals in the vicinity of the haulout in addition to the proportion of these animals that choose to go ashore.

Photographic Identification

Unique markings on the pelage of harbor seals are distinguishable to the human eye (Crowley *et al.*2001). With minimal training, observers can visually recognize the ventral pelage patterns of individual seals, providing an important tool in population and life history studies. This method of categorizing seals by sex and color morph provided an effective, low cost means of marking and recapturing seals (Crowley *et al.* 2001). Accessibility and visibility of seals are crucial to the application of this technique. Tugidak Island provided an ideal geographic situation to identify individual seals, which may not be readily available at other sites. Weather conditions, photographer experience, and the proximity of seals to observers are factors that may limit the ability to consistently produce high quality photographs.

Although we successfully estimated abundance using photographic identification, in hindsight we would recommend several improvements to streamline the process. Fatigue-induced errors could be reduced by limiting the number of images that need to be evaluated. Replicate photographs of individual seals may not be necessary because we found that multiple images of the same seal were of similar quality. The majority of images we rejected were due to improper orientation of the seal or an obscured ventrum; blurry, overexposed, or underexposed photographs made up a small percentage of the rejected images. Digital photography had an advantage over film by allowing photographers to immediately evaluate the quality of photographs and make necessary compensations in the field. Observers were liberal in photographing seals to ensure that all seals were identified; with experience, poorly positioned animals could be eliminated prior to photography, reducing the number of images visually evaluated. With more experienced observers, we recommend using the more detailed classification scheme developed by Crowley *et al.* (2001). Although characteristics such as spot complexity and ring density can be subjective, humpback whale (*Megaptera novaeavangliae*) and seal research has demonstrated that these types of marks provide valuable information that can be used by trained observers to consistently categorize animals, dramatically reducing the number of image comparisons (Mizroch *et al.* 1990, Yochem *et al.* 1990).

The condition of the pelage with regards to molting should also be considered when photographing seals. Seals that have recently completed molting exhibit a higher contrast between markings and background of the pelage providing better images for visual matching. This study was conducted throughout the molting period when numbers ashore are higher. Photographically identifying seals after all segments of the population have completed molting might offer more information per unit of effort, resulting in more precise population estimates.

Population Estimate

From our 11 population estimates, we detected a decline in the number of seals available to come ashore on the southwestern beach of Tugidak Island. The high variance of these estimates was likely derived from the relatively small number of recaptured seals ($\hat{m}_2$). The ratio of identifiable to unidentifiable seals was low because "bleached" seals were included at the time of recapture. To compare our results to those of other studies it was necessary to conduct our study during August and September, when "bleaching" of the pelage was most likely to occur (Pitcher 1990, Mathews and Kelly 1996, Withrow and Loughlin 1996, 1997, Frost *et al.* 1999, Jemison and Kelly 2001, Boveng *et al. 2003,* Small *et al.* 2003, Ver Hoef and Frost in press).

Despite the wide confidence intervals, we believe our capture-recapture estimates and their linearized replacements were unbiased. The assumptions of the Chapmanized Petersen estimates were generally achieved (Seber 1982). It is highly unlikely that photographing seals affects the probability of capture, and we corrected for the probability of not detecting a match as "tag loss". Based on our observations of seals ashore, we assumed that enough time had elapsed between capture and recapture to permit a random sample at the time of recapture.

When compared to other studies we found our population estimates to be reasonable. Violations of the assumption of a closed population tend to inflate population estimates (Seber 1982). Movements among haulouts are at their lowest during the month immediately preceding molting (Lowry *et al.* 2001 – the radio tags employed did not permit movement estimates during the molt), and our short interval between capture and recapture should minimize the effects of any migration that does occur. "Bleached" seals would effectively function as migrants if their molt condition changed between the time of capture and recapture, but the short intervals we used also minimized this possibility.

Our counts of seals ashore gave us a minimal population size to compare with our estimates. We further evaluated our estimates by comparing published count correction factors to the ratio of our counts to our population estimates. On average, our linear capture-recapture abundance estimates differed from the daily peak counts by a factor of 1.94, which was roughly in accord with those reported elsewhere. A correction factor of 1.90 during the molting period was estimated using radio tags deployed near Cordova, Alaska (Withrow and Loughlin 1996), and a correction factor of 1.74 estimated from Grand Island in southeastern Alaska (Withrow and Loughlin 1995). Although these studies were geographically the most proximate to our study site, it should be noted that these sites differ from Tugidak Island in substrate and tidal influence. Huber *et al.* (2001) reported a correction factor of 1.54 for the pupping period along the Washington and

Oregon coast. In British Columbia, correction factors for aerial surveys derived from behavioral data obtained from time-depth recorders ranged from 1.36 to 1.62 with a mean of 1.53 (Olesiuk 1999).

Covariate Analysis

Seal counts were consistent among observers and spanned contrasting tide heights, times of day, and dates. Unfortunately, relatively warm, clear weather with a lack of precipitation persisted throughout the molting period, reducing contrast in weather related covariates. While this made it difficult to fully evaluate the effects of weather on seal haulout behavior, a lack of variability in weather conditions accentuated the effects of non-weather related covariates by reducing background noise.

Based on observational data, we noted a generalized daily pattern of seals coming ashore on the southwestern beach of Tugidak Island during the molting period. In the early morning, we observed seals swimming northwest parallel to the coast (less than 100 m offshore), eventually coming ashore on the beach. The number of seals arriving at the beach in this manner peaked during mid to late morning. Seals usually continued to arrive at the beach until early afternoon.

Upon coming ashore, most seals seemed to remain in one location on the beach, although a few individuals would reenter the water for short periods. In the event of a disturbance early in the day, seals entering the water remained near the beach, generally hauling out within an hour. A disturbance later in the day resulted in seals leaving the area and not returning until at least the following day.

During the late afternoon and early evening, the daily migration pattern reversed. Seals began to leave the beach swimming southwesterly. Seals seemed particularly sensitive to disturbance and rising tides as the evening progressed. Rather than move up the beach in response to the rising tide or hauling out again after a disturbance, seals often entered the water and left the area.

Our most parsimonious model of the proportion ashore included time of day, tide height, rate of tidal change and wind speed as predictors. When we examined the fit of the model, we found the model was better at predicting the proportion of seals ashore under favorable and poor conditions than under intermediate conditions.

Time of day – Surveying seals on Tugidak Island at low tide may produce less than optimal results. Time of day exhibited a strong effect on the proportion of seals ashore on Tugidak Island. We found the number of seals ashore peaked in the afternoon and remained high through the evening (Figure 1). In contrast, Small *et al.* (2003) found counts of seals ashore in the Kodiak area highest one hour after solar noon (approximately 1500 local time). We suspect that the prolonged peak at Tugidak Island may be partially explained by a greater number of observations later in the day.

Frost *et al.* (1999) and Ver Hoef and Frost (in press) also found the proportion of harbor seals ashore in Prince William Sound was significantly affected by time of day. Unlike on Tugidak Island, the number of seals ashore in Prince William Sound peaked during the morning hours. Boveng *et al.* (2003) found a prolonged peak from 1100-1400 local solar time for seals in the Gulf of Alaska.

Seal surveys in Alaska are often centered on the low tide that occurs during daylight hours, which may be the optimal time for many sites in Alaska (Withrow and Loughlin 1995, 1996, 1997; Frost *et al.* 1999; Small *et al.* 2003). However, during August and September when surveys are flown, the preferred low tide on Tugidak Island generally occurs before noon, when numbers ashore are generally increasing and variable. Based on NOAA tide tables, this occurrence appears consistent between years on Tugidak Island.

Tide height – Other researchers have found that the number of seals ashore on terrestrial haulouts in Alaska is negatively correlated with tidal height and tends to increase around the time of low tide (Frost *et al.* 1999, Boveng *et al.* 2003, Ver Hoeff and Frost in press, Small *et al.* 2003). Lower tide heights increase the amount of exposed substrate, permitting higher numbers of seals ashore. However, the tide height effect we estimated differed from that of other studies in Alaska. We estimated that the proportion of seals ashore would be highest in the middle tide ranges (approximately 1.5 m above mean low water), with a lower proportion ashore at higher and lower tide heights (Figure 2).

This atypical reaction to tide height may be partially explained by the configuration of the southwestern beach on Tugidak Island. With the exception of extreme high tides or high tides in combination with high surf conditions, haulout space on the beach is generally not limited. The decrease in proportion ashore at higher tides is likely a function of seals being displaced as water levels approach the base of the bluffs, covering the beach. The decline in the proportion of seals ashore at lower tides is more difficult to interpret. During extremely low tides, an offshore bar, parallel to the beach, becomes visible. Seals seem reluctant to cross this bar and remain in the water until the bar is sufficiently covered by the incoming tide.

When we remove the extreme high and low tide events, tide height appears to have little effect on the proportion of seals ashore (Figure 2). In other locations, when tide height does not restrict the amount of area available to seals for hauling out (such as wide beaches and glacial sites), it has also been found to have a minimal effect on the number of seals ashore (Stewart 1984, Boveng *et al.* 2003). Our results support the hypothesis that tide height influences the number of seals ashore by limiting the availability of a suitable substrate, rather than being related to another factor (e.g. such as better feeding opportunities at specific stages of tide).

Tide change - We detected a decrease in proportion of seals ashore as the rate of tide change increased (Figure 3). A falling tide would generally leave hauled out seals high on the beach, whereas a rising tide disturbed seals, forcing them to either move up the beach or vacate the beach. During the afternoon and evening, seals tended to leave the beach on a rising tide. The slight decline in the estimated proportion of seals ashore during rapidly falling tides may simply be a function of sparse data at lower ranges. When aerial surveys attempt to bracket the low tide, the probability of being ashore on a rising tide may be different than on a falling tide for the same tide height, further complicating interpretation of count data. Using categorical data such as high, low, rising and falling, may not be sufficient to describe changes in seal haulout behavior with regards to tide.

(Thompson and Harwood 1990, Mathews and Kelly 1996, Frost *et al.* 2001). Our data suggest that dispersal may have a greater influence on Tugidak Island.

Other covariates - A high-pressure weather system persisted over Tugidak Island for much of the study period, producing constant weather patterns. Extended periods of sunny, breezy days resulted in little contrast in weather conditions. During our study, temperature, precipitation, cloud cover, and wind speed did not significantly influence the probability of seals being hauled out. However, our qualitative observations suggest that weather did influence harbor seal haulout behavior to some degree.

Temperature did not seem to affect the number of seals ashore. A lack of response to temperature is expected given Tugidak Island does not experience the extreme high temperatures found in the southern range of the species (Watts 1992). As with wind, the measured temperature data may not have accurately reflected conditions on the haulout. Factors such as evaporative cooling from wet sand, shadows from the bluffs, or a cooling effect from the ocean on the microclimate of the haulout were not evaluated.

An exceptionally dry summer provided little information on precipitation. One brief hailstorm caused seals to rapidly leave the beach. The intensity of rainfall seemed to influence seal behavior. Rather than recording the presence/absence of precipitation, a better predictor may be a continuous variable incorporating the intensity of precipitation. Cloud cover seemed to have little effect on the number of seals ashore.

Wind direction was also difficult to quantify. A lack of contrast made it difficult to speculate on the effects of wind direction. We suspect that winds parallel to the beaches would have a greater effect than those from other directions due to the protection offered by the bluffs.

Weather variables on Tugidak Island tended to be strongly correlated. A possible solution to analyzing how weather affects haulout behavior would be to model the combined effects of measurable weather conditions as a single variable similar to the thermal index of heat flux describe by Watts (1992).

Day Effect

To evaluate the possibility that observations within a day were independent, we assumed that the true effect of day fell between the extremes of each observation being independent and each day being a set of replicate observations. We found that the conservative approach of assuming the degrees of freedom in our data were equal to the number of days rather than the number of counts had a minimal effect on the final model selection. The only difference in the highest ranked model was that the effect of wind speed was not included under our more conservative approach, whereas all other factors included in the model ranked highest initially (time of day, tide height, rate of change in tide, and surf) were retained.

Interactions

Our qualitative observations of seal behavior suggest that there may be interaction between covariates in their effect on the proportion of seals ashore, although these seemed most pronounced during extreme conditions (e.g., high surf at high tide).

Because these circumstances were rarely encountered during our study, estimating these effects would have been difficult. Disturbances (both natural and anthropogenic) were likely to produce complicated interactions with other covariate (*e.g.* a disturbance in the evening may result in seals abandoning the haulout for the rest of the day, as compared to morning, when seals return to the beach following a disturbance).

Conclusions

Understanding the relationship between the number of animals counted ashore and the true population is essential for using harbor seal count data to estimate trends and abundance. When population parameters are derived from counts of seals ashore, the timing of surveys should ideally coincide with the least amount of daily and seasonal variation, increasing the precision and accuracy of counts. Additionally, seals counted ashore should reflect the age and sex composition of the entire population. Reported shifts in the timing of the molt between years (Jemison and Kelly 2001) could be the result of shifts in the population structure leading to an observed shift in the timing of seals ashore. A population with a high proportion of young animals would have an early peak in numbers ashore versus a population of older animals (Daniel *et al.* 2003). Interpreting demographic shifts is may be necessary for evaluating between year trends.

To minimize covariate effects, the "best" times to count seals ashore on Tugidak Island during the molting period are in the afternoon during late July and early August when the numbers of seals ashore are high and stable. There are some caveats to restricting surveys to a narrow set of conditions. A lack of contrast may lead to a limited understanding of covariate effects (such as not detecting an unexpected local effect like the decline in the number of seals ashore at extreme low tides on Tugidak Island). There is also a possibility that seals ashore may not be representative of the total population (Thomson and Rothery 1987, Härkönen *et al.* 1999 Härkönen and Harding 2001, Daniel *et al.* 2003). A broad survey window under contrasting conditions would provide a better estimate of covariate effects (Adkison *et al.* in press); however, if the survey window were too wide these counts might not be replicates, but rather counts of separate groups of animals of differing demographic composition. On Tugidak Island, August and September appear to be a highly dynamic period in terms of both the abundance and demography of seals ashore.

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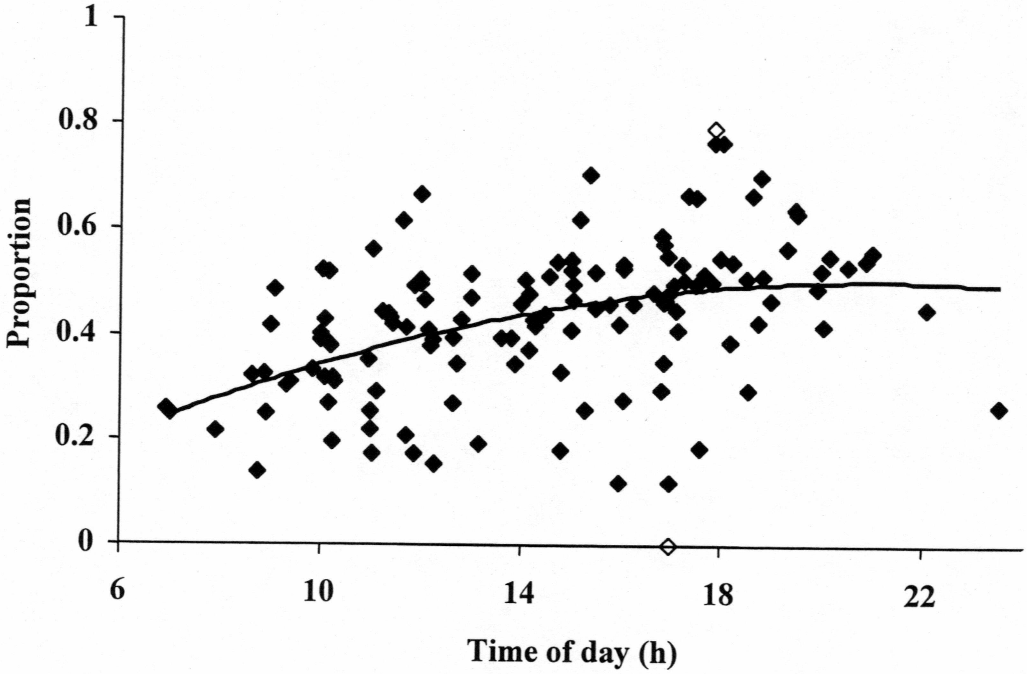

Figure 1. Proportion (diamonds, open diamonds indicate a Winsorized observation) of harbor seals ashore on the southwestern beach of Tugidak Island and the estimated effect of time of day (solid line).

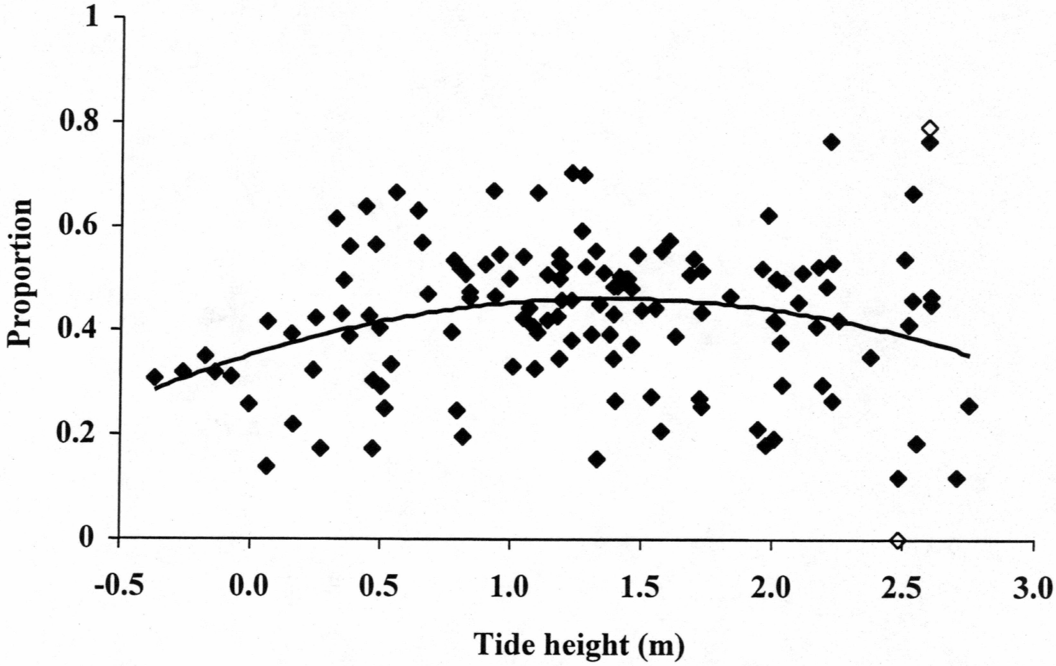

Figure 2. Proportion (diamonds, open diamonds indicate a Winsorized observation) of harbor seals ashore on the southwestern beach of Tugidak Island and the estimated effect of tide height (solid line).

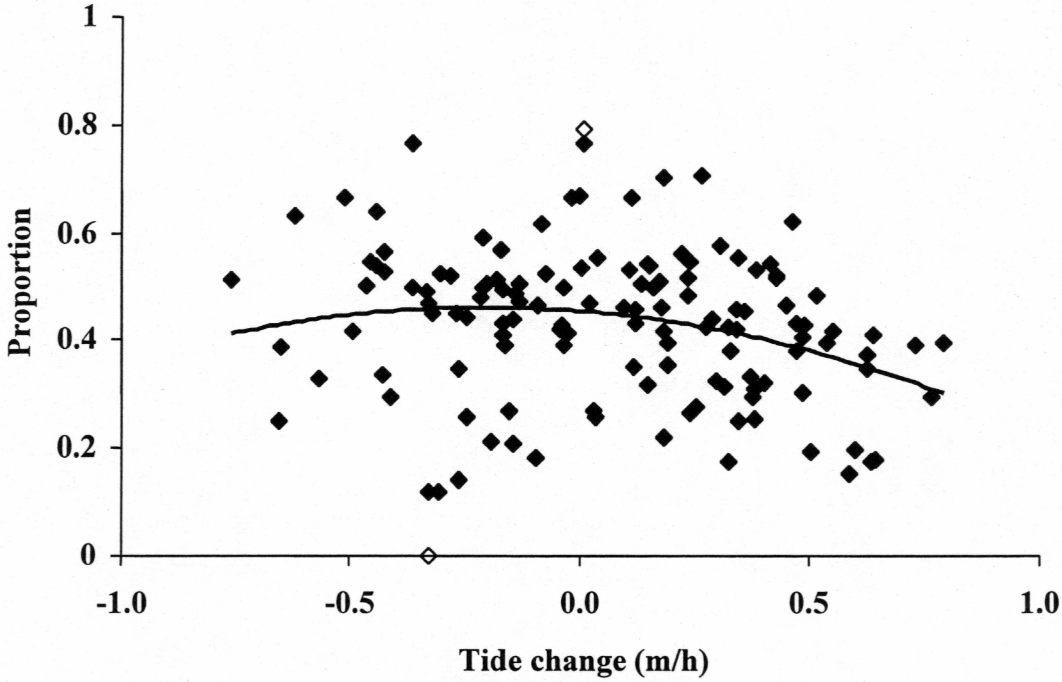

Figure 3. Proportion (diamonds, open diamonds indicate a Winsorized observation) of harbor seals ashore on the southwestern beach of Tugidak Island and the estimated effect of tide height (solid line).

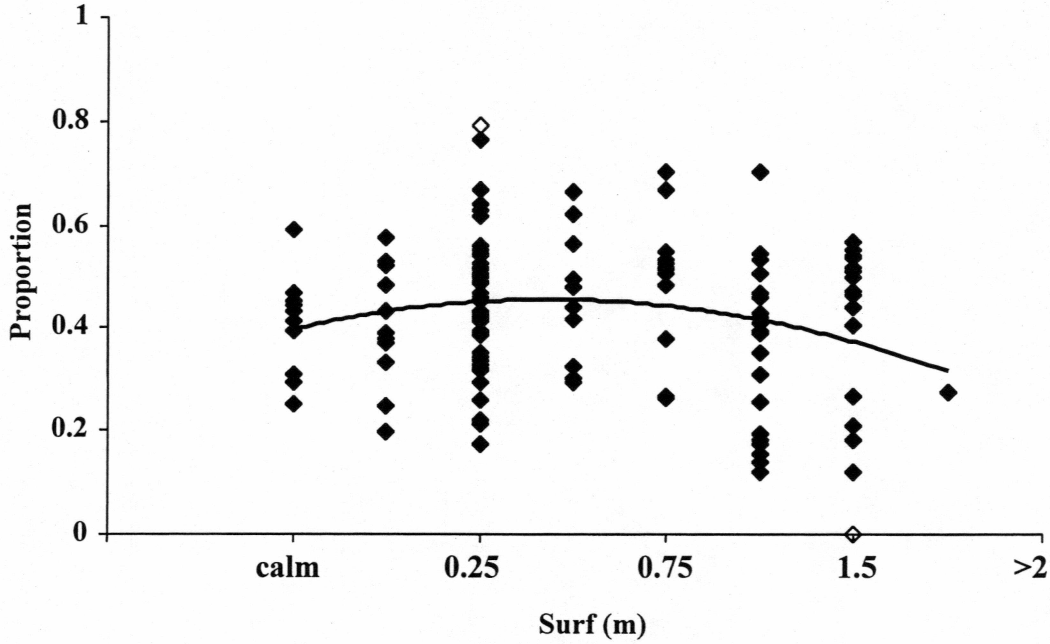

Figure 4. Proportion (diamonds, open diamonds indicate a Winsorized observation) of harbor seals ashore on the southwestern beach of Tugidak Island and the estimated effect of surf (solid line).

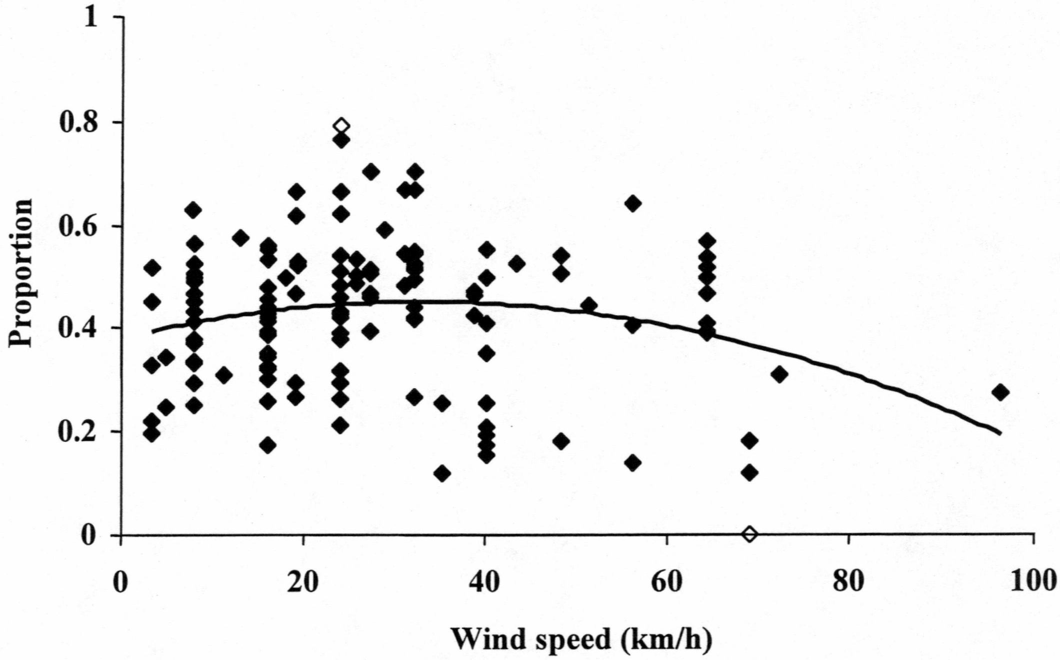

Figure 5. Proportion (diamonds, open diamonds indicate a Winsorized observation) of harbor seals ashore on the southwestern beach of Tugidak Island and the estimated effect of wind speed (solid line).

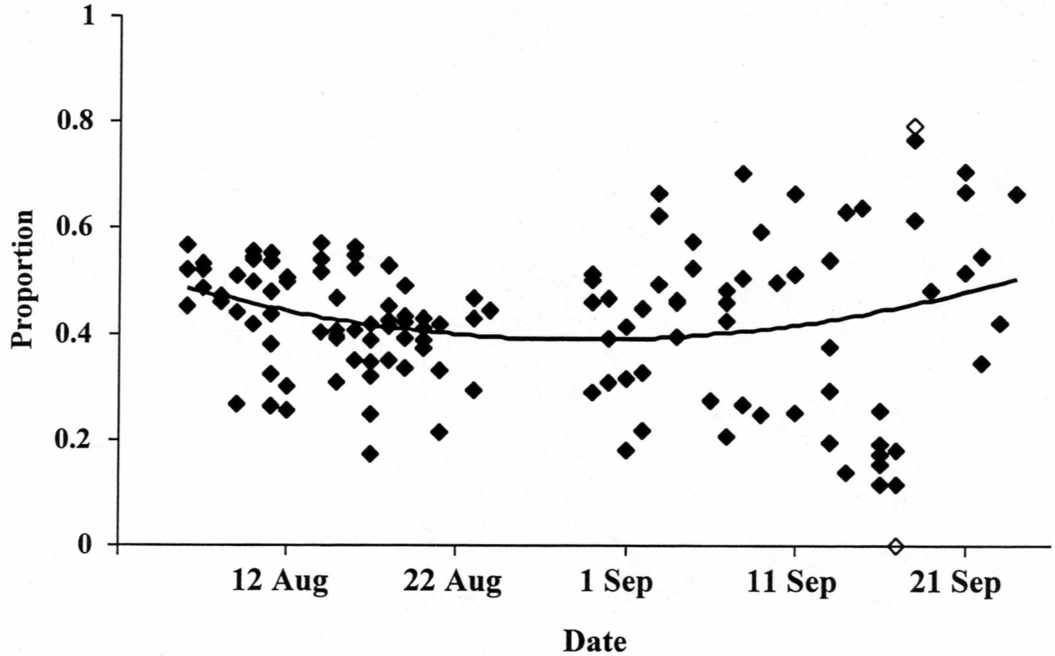

Figure 6. Proportion (diamonds, open diamonds indicate a Winsorized observation) of harbor seals ashore on the southwestern beach of Tugidak Island and the estimated effect of date (solid line).

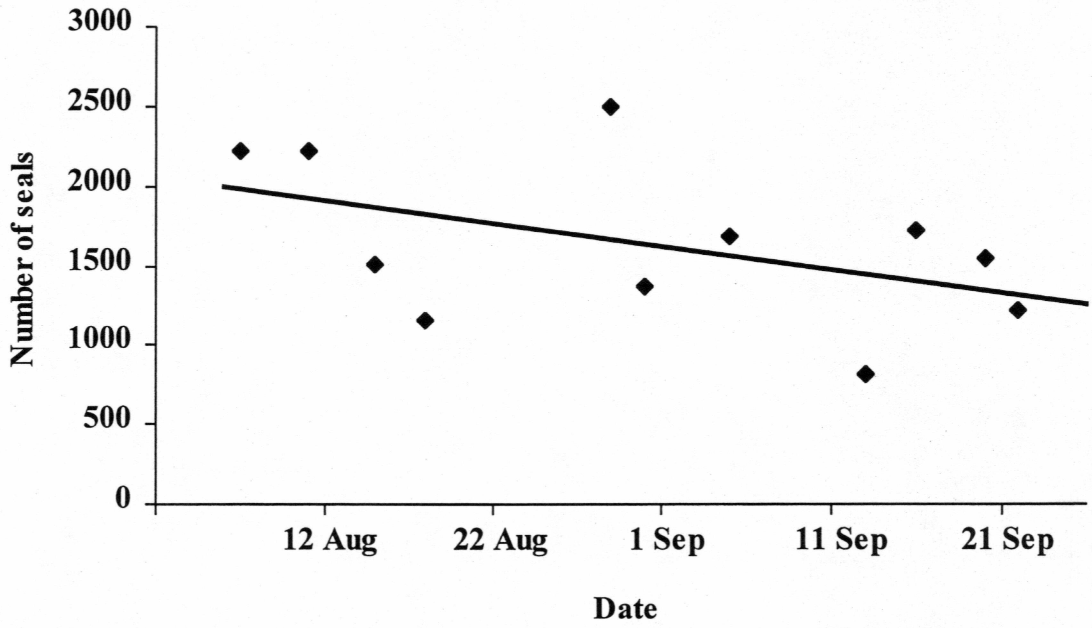

Figure 7. Capture-recapture estimates (diamonds) of the number of seals available to come ashore on the southwestern beach of Tugidak Island, Alaska (95 % confidence intervals are given in Table 1). These estimates were replaced by a linear trend (horizontal line) for the purpose of modeling the effects of the covariates.

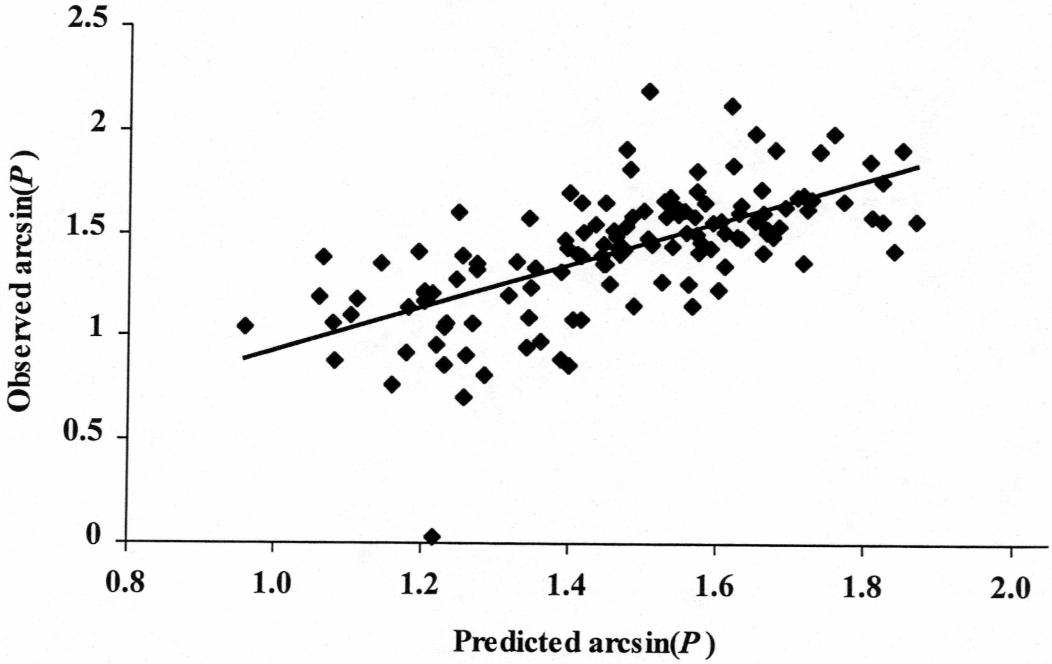

Figure 8. Arcsine transformed observed and predicted proportions (diamonds) of harbor seals ashore on the southwestern beach of Tugidak Island, Alaska. The solid line indicates a perfect match between predicted and observed.

Table 1. Estimated number of seals using the southwestern beach of Tugidak Island, Alaska (n_1 = the number of seals marked on day 1, n_2 = the number of seals captured on day 2, m_B = the number of seals marked on day 1 and recaptured on day 2 using our matching method, $\hat{m}_B$ = number recaptured, inflated to account for "marked" seals whose photographs failed to match, $\hat{N}_B$ = the estimated number of seals available to haul out, CV = coefficient of variation for $\hat{N}_B$).

	7 Aug	11 Aug	16 Aug	18 Aug	3 Sep	5 Sep	8 Sep	11 Sep	13 Sep	16 Sep	18 Sep
n_1	37	112	79	113	148	221	168	141	96	95	235
n_2	323	196	254	182	249	181	148	110	100	241	134
m_B	4	8	12	15	12	16	12	15	4	12	22
$\hat{m}_B$	4.5	9.1	13.6	17.0	13.6	18.2	13.6	17.0	4.5	13.6	25.0
$\hat{N}_B$	2228	2223	1503	1156	2495	1366	1686	818	1714	1548	1216
CV	0.36	0.28	0.22	0.20	0.23	0.19	0.23	0.19	0.37	0.23	0.16
Lower 95%CI	1247	1433	1084	870	1758	1037	1197	621	930	1109	981
Upper 95%CI	7892	5599	3176	2268	5350	2632	3597	1592	6260	3284	2138

Table 2. Likelihood ratio test for covariates affecting the proportion of harbor seals ashore (χ^2 Critical value = 5.99 at α = 0.05 with 2 degrees of freedom).

Covariate	Deviance	χ^2 stat.
Time	8.81	30.62
Tide height	10.32	9.91
Δ Tide	10.40	8.93
Surf	10.55	7.03
Wind speed	10.60	6.36
Date	10.66	5.59
Precipitation	10.80	3.98
Cloud cover	10.83	3.55
Sine (Wind direction/2)	10.98	1.77
Temperature	11.11	0.22
Null	11.13	0.00

Table 4. Coefficients and intercepts (standard errors in parenthesis) of generalized linear models of the arcsine of the proportion of harbor seals being ashore.

	Model	
	Time, Tide height, Δ Tide, Surf, Wind speed	Time, Tide height, Δ Tide, Surf
Intercept	-0.161 (0.346)	-0.230 (0.347)
Time	0.163 (0.041)	0.171 (0.046)
Time^2	-0.004 (0.093)	-0.005 (0.002)
Tide ht.	0.256 (0.002)	0.258 (0.093)
Tide ht.^2	-0.133 (0.002)	-0.133 (0.033)
Δ Tide	-0.188 (0.121)	-0.181 (0.122)
$\Delta\ \text{Tide}^2$	-2.07 (0.618)	-2.14 (0.615)
Surf	0.203 (0.145)	0.294 (0.136)
Surf^2	-0.059 (0.028)	-0.071 (0.025)
Wind speed	0.008 (0.004)	
Wind speed^2	-0.00009 (0.0005)	

APPENDIX

Several aspects of our study permitted errors in identification to be treated as tag loss. Firstly, in a single capture – recapture experiment it is not necessary to identify an individual beyond the capture period. Secondly, each population estimate we made was independent; as a result, the effects of misidentification are not cumulative as described by Stevick *et al*. (2001). Thirdly, all of the seals used in our population estimate could potentially be identified; matching errors were the result of individuals not being recognized at the time of recapture, the equivalent of a lost tag. By independently matching the same set of images, we were able to determine the estimated probability of missing a match using our method (π_B). By treating matches made by Hastings[1], using methods modified from Hiby and Lovell (1997), as a second method of "tagging", we can use double tagging theory to estimate (π_B).

$$\pi_B = \frac{m_A}{m_A + m_{AB}}$$

where:

m_A = the set of seals matched only by Hastings (13 seals)[1].

m_{AB} = the set of seals matched by both Hastings and matched by us (96 seals)[1].

[1] Personal communication from Kelly Hastings, Alaska Department of Fish and Game, Division of Wildlife Conservation, 333 Raspberry Road Anchorage, Alaska 99518, U.S.A.

We calculated the estimated correction factor (c) for the number of recaptured seals ($\hat{m}_2$) including those not detected by our method (false negative matches).

$$c = 1/(1 - \pi_B)$$

where:

π_B = the estimated probability of missing a match with our method.

Therefore, $(\hat{m}_2) = cm_2$, where m_2 is the number matched by our method

We used the normal approximation to calculate 95% confidence intervals for our population estimates.

$$\frac{\left(m_2 - \frac{n_1 n_2}{N^*}\right)^2}{\left(\frac{n_1 n_2}{N^*}\right)^2 \frac{\pi_B}{1-\pi_B}/X + \frac{n_1 n_2}{N^*}\left(1 - \frac{n_1}{N^*}\right)\left(\frac{N^* - n_2}{N^* - 1}\right)} = 1.96^2$$

where:

N^* = the population estimate.

n_1 = the number of seals photographed during a capture period.

n_2 = the number of seals photographed plus the number of properly oriented seals "skipped" due to poor pelage condition during a recapture period.

m_2 = the number of recapture (seals from a capture period identified during a recapture period).

π_B = the estimated probability of missing a match with our method of matching.

X = the tag loss sample size.

To stabilize the variance in our proportional data we used an arcsine transformation.

$$\varphi = arcsin\sqrt{\frac{X}{N+1}} + arcsin\sqrt{\frac{X+1}{N+1}}$$

where:

ϕ = the transformed proportion of seals ashore.

X = the number of seals ashore.

N = the estimated number of seals in the population from our linear trend.

Evaluating plots of both transformed and untransformed observations suggested that the transformation did not alter the character of the data for covariate analysis; there was a monotonic and quasi-linear relationship between the proportion ashore and the transformed proportion ashore.

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"Working with Aboriginal Elders"

An Introductory Handbook for Institution-Based and Health Care Professionals
Based on the Teachings of Aboriginal Elders and Cultural Teachers

By: Jonathan H. Ellerby

Based on the teachings and experience of a select group of local Elders and Cultural Teachers, this manual addresses common and widespread areas of institutional conflict and concern in a manner that identifies solutions and provides information necessary for health care professionals and program administrators to work effectively with Elders. Though focused on health care institutional issues, the material is naturally transferable to most institutional settings, including corrections, education, research, and justice.

The first section addresses questions raised by health care professionals working directly with Elders, such as:

- Who is an Elder?
- How is an Elder Trained?
- What does an Elder do?
- What is the appropriate protocol when working with an Elder?

The second section addresses administrative issues involving Elders, such as: the hiring process, payment, teamwork, confidentiality, and time commitments.

Working with Aboriginal Elders
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